Grove Mountains 99027 – 10 grams
Intermediate Olivine-phyric Shergottite

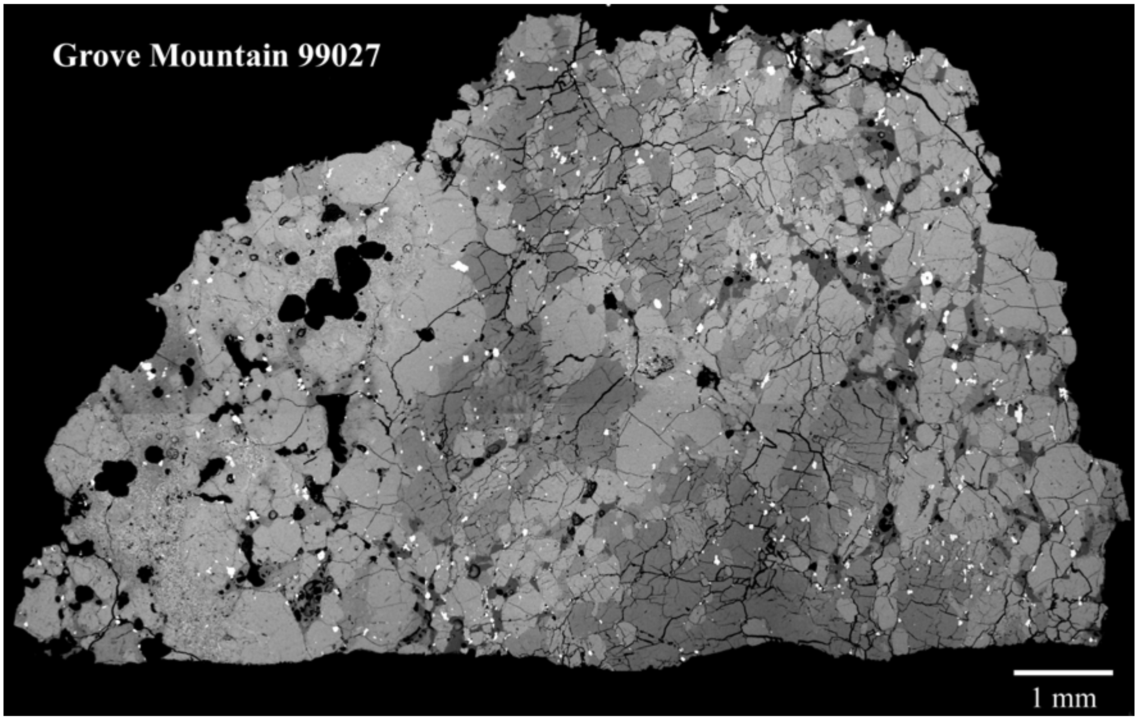

Figure 1: Back-scatter-electron image of thin section of GRV99027 (kindly provided by Yunbin Guan and Lauri Leshin) (see also figure 2 in Hsu et al. 2004). Dark gray is pigeonite, light gray is olivine. Melt pocket is on left.

Introduction
Lin *et al.* (2002, 2005, 2008), Wang et al. (2002) and Hsu et al. (2004) reported a new Martian meteorite from Grove Mountains, Antarctica, collected by the 16th Chinese Antarctic Research Expedition in 1999. It is shaped like a rounded cone and is partially covered with fusion crust (figure 2).

GRV99027 is a "lherzolitic shergottite", but from an "intermediate" mantle source. The age has been determined to be 177 m.y.

The smaller the rock the better the mineralogic description (QUE, LEW, GRV).

Petrography
GRV99027 consists of mostly olivine and pyroxene and has both poikilitic and interstitial lithologies. Like other "lherzolitic shergottites", GRV99027 also has partially devitrified "melt pockets" of impact glass (see figure 1). A small amount of maskelynite, troilite, chromite and phosphate (merrillite) can be found in the intersticies between the olivine and pyroxene. The texture and mineral composition appears similar to that of ALH77005 (Hsu et al. 2004, Lin et al. 2005, 2008).

Olivine and pyroxene exhibit undulose extinction, plagioclase has been partially shocked to maskelynite and several grains of olivine show granulation. The shock stage is S4, weathering grade W1 (Russell *et al*. 2002).

Mineral Chemistry
Olivine: Small, rounded olivine is poikilitically enclosed in large oikocrysts of pigeonite. The composition of

Modal Mineralogy for GRV99027
From Lin et al. (2005)

	Poikilitic	Interstitial	Bulk
Olivine	30.9	33.9	32.1
Opx	66.4	38.3	55.4
Cpx	1.4	10.4	5
Chromite	1.2	0.9	1.1
Ilmenite		tr	tr
Plagioclase		14.6	5.8
Merrilite		1.4	0.5
Sulfide		0.4	0.2

Figure 2: *Photo of GRV99027 contributed by Weibiao Hsu (see Hsu et al. 2004).*

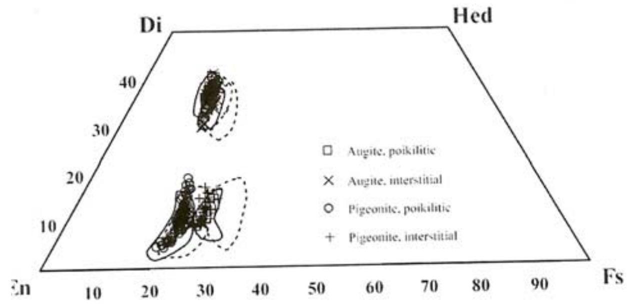

Figure 3: *Composition of pyroxene in GRV99027 (from Lin et al. 2005). The solid line includes data for ALH77005 and the dashed lines LEW88516, showing that GRV is similar to other "lherzolitic shergottites".*

olivine is Fo_{70-76}. Olivine in the poikilitic region is slightly more magnesian than in non-poikilitic regions (Lin et al. 2005). Trapped-melt inclusions are found in olivine.

Pyroxene: Pigeonite oikocrysts are rather homogeneous and sometimes exhibit augite exsolution (?) around the rims (Hsu et al. 2004). The composition of pigeonite is $En_{74}Fs_{22}Wo_{4}$. Augite ($En_{53}Fs_{15}Wo_{32}$) is found separately in non-poikilitic regions. Orthopyroxene $En_{78}Wo_{2}$ has FeO/MnO ratio = 34 ± 5. Figure 3 shows that the pyroxene in GRV99027 has the same range in composition as in ALH77005 (Lin et al. 2005).

Plagioclase: Plagioclase (An_{44-57}) has been partially converted to glass by shock.

Opaque Oxides: Euhedral chromite is mainly enclosed in pyroxene.

Phosphates: Merrillite grains up to 150 microns are found interstitial to olivine, pyroxene and plagioclase (Guan et al. 2003). They are found to contain small apatite grains and some veins of plagioclase glass. Seven grains of merrillite were analyzed for REE by Hsu et al. (2004).

Whole-rock Composition

Lin et al. (2008) reported the bulk chemical composition (Table 1, figure 4). Hsu et al. (2003, 2004) determined the REE content of the melt glass and individual minerals. From this and the mode they were able to model the REE pattern for the rock. Since the REE are found mainly in the merrillite, this model is critically dependent on the merrillite content (0.1 to 0.5%).

Lin et al. also determined the chalcophile and highly siderophile elements (figure 5). Ga and W are found to be relatively high in GRV99027 (and other Martian rocks), indicating that the source region of Martian magma was not in equilibrium with a metal core (Lin et al. 2008).

The REE content of the melt glass is elevated above the value calculated for the bulk rock, probably due to selective melting of some phosphates.

Radiogenic Isotopes

GRV99027 yields a Rb-Sr mineral isochron age of 177 ± 5 m.y. and an initial $^{87}Sr/^{86}Sr$ ratio of 0.710364 (figure 6). The initial ^{143}Nd ratio is estimated at +12.2, assuming an age of 177 m.y., along with the Sm-Nd and Nd isotope ratio of whole rock composition (Liu et al. 2011).

Terrestrial Weathering (?)

Hsu et al. (2004) report that olivines and pyroxenes in GRV99027 commonly display light REE enrichment and have a negative Ce anomaly that they interpret as due to "terrestrial weathering".

Other Isotopes

The deuterium/hydrogen ratio (D/H) of phosphates in GRV99027 has been found to be high and variable (Guan et al. 2003). This high D/H ratio is enough to verify the Martian origin of this sample.

References for GRV99027

Table 1: Chemical composition of GRV 99027.

reference	Lin et al. 2008	
weight		
SiO2	43.2	
TiO2	0.34	(a)
Al2O3	2.06	(a)
FeO	19.2	(a)
MnO	0.46	(a)
CaO	3.4	(a)
MgO	29.7	(a)
Na2O	0.42	(a)
K2O	0.019	(a)
P2O5	0.25	(a)
sum		
Li ppm		
Be		
S		
Cl		
Sc ppm	21.4	(b)
V	122	(b)
Cr	7200	(b)
Co	65.6	(b)
Ni	314	(b)
Cu	4.23	(b)
Zn	59	(b)
Ga	7.4	(b)
Ge ppb	606	(b)
As		
Se		
Br		
Rb	0.717	(b)
Sr	7.5	(b)
Y	4.77	(b)
Zr	15	(b)
Nb	0.455	(b)
Mo		
Pd ppb	10	(b)
Ag ppb		
Cd ppb		
In ppb		
Sb ppb		
Te ppb		
I ppm		
Cs ppm	0.035	(b)
Ba	3.66	(b)
La	0.196	(b)
Ce	0.499	(b)
Pr	0.076	(b)
Nd	0.452	(b)
Sm	0.254	(b)
Eu	0.138	(b)
Gd	0.568	(b)
Tb	0.105	(b)
Dy	0.731	(b)
Ho	0.155	(b)
Er	0.433	(b)
Tm	0.06	(b)
Yb	0.366	(b)
Lu	0.053	(b)
Hf	0.438	(b)
Ta		
W ppb	0.455	(b)
Re ppb		
Os ppb	2.5	(b)
Ir ppb	2.4	(b)
Au ppb		
Tl ppb		
Bi ppb		
Th ppm	0.031	(b)
U ppm	0.009	(b)

technique: (a) ICP-AES, (b) ICP-MS

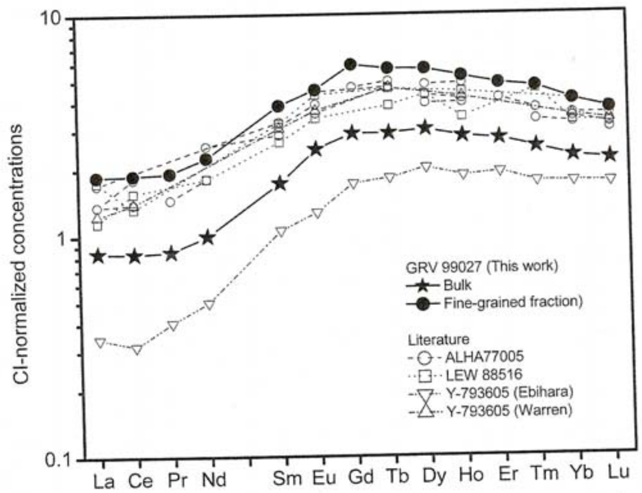

Figure 4: *Normalized rare-earth-element diagram for GRV99027 compared with other "lherzolitic shergottites" (from Lin et al 2008).*

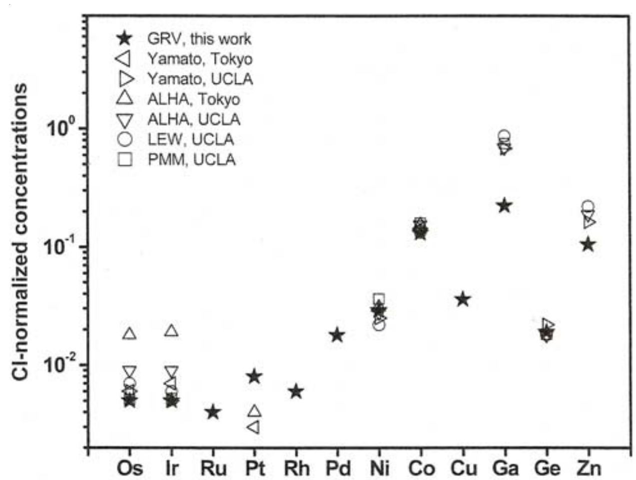

Figure 5: *PGE, chalcophile and highly siderophile elements in GRV99027 (from Lin et al. 2008).*

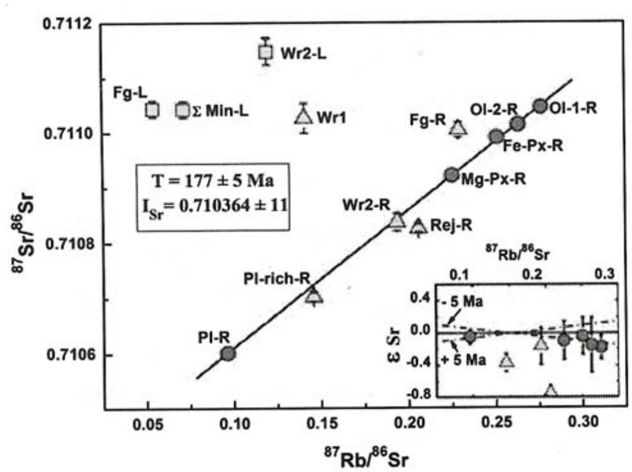

Figure 6: *Rb-Sr isohron for GRV99027 (from Liu et al.2011).*